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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF ENTOMOLOGY
FOREST INSECT INVESTIGATIONS

EXPERIMENTS WITH THE MOUNTAIN PINE BEETLE

IN THE PREVENTION OF ATTACKS AND KILLING OF BROODS

by

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March 26, 1928

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EXPERIMENTS WITH THE MOUNTAIN PINE BEETLE
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INTRODUCTION

During the past few years increasing demands have been made upon the Bureau of Entomology for a reliable method of preventing barkbeetle attacks upon forest trees. A method of killing beetle broods in trees without injury to the hosts, thus making possible the saving of trees even after attack by barkbeetles, is also desired.

The need for such methods has been very acutely felt in the National Parks, for the aesthetic appeal of these places is in a large degree dependent upon the forest trees which are one of the outstanding natural features. Since these recreational areas are each year attracting larger numbers of the population, they are becoming increasingly valuable to the nation at large, and the preservation of the present forest stands becomes yearly of greater importance. Yet during the last few years beetle attacks have resulted in the destruction of forest stands and of individual trees which had added most to the recreational value of these areas.

Similar demands have come from the national forests, where much the same conditions prevail.

There is a distinct need also among owners of shade and ornamental trees for means of giving these trees this same protection.

Practically all the previous investigations undertaken by the bureau have had as their object the protection of commercial forest stands, and ~~and~~ the methods of control developed have been designed to decrease or eliminate beetle infestations. Very little has been done to develop methods of preventing insect attacks on individual trees or of saving trees that had suffered attack, and the bureau has been unable to advise those desiring to effect these ends.

The history of previous experiments in this phase of control of barkbeetles and barkborers can be written in a few words, and the published information dealing with the subject is very limited.

Prevention of attack on living trees has been attempted in two general ways, viz., by spraying the trunks or other parts of trees with material having an action repellent to the insects, and by erecting mechanical barriers around the portion of the trunk attacked. Considerable work has been done in preventing insect attacks on crude forest products, though the methods employed have been applied only in a limited way to living trees. Craighead¹ experimented with various repellent sprays to prevent attack on cut logs, and attacks on this material have also been prevented by cutting the trees at certain

¹ Craighead, F.C.Bull.No.1079,U.S.D.A.; Experiments with Spray Solutions for Preventing Insect Injury to Green Logs; 1922.

periods and by proper seasoning. Both Craighead and Hopkins² have recommended the latter method as being effective. Burke³ gives many references to the use of sprays, coatings and mechanical barriers to prevent attacks of Buprestid barkborers.

The prevention of attack on living trees has been suggested by the Lipman-Gordon method of tree injection⁴. This consists of injecting certain substances into trees, and has been recommended by these workers as a cure for the chestnut blight fungus and for chlorosis in orchard trees. In conversation with Mr. C.B. Lipman in the spring of 1926, the writer learned that experimentation with the method had given promise of success in preventing attacks of aphids on orchard trees. The use of this method in a modified form to prevent attacks of the mountain pine beetle in lodgepole pine is one phase of the experimental work reported in this paper.

²Hopkins, A.D., Bull. 58, Part V, U.S.D.A., Bur. Ent.; Some Insects Injurious to Forests. Insect Depredations in North American Forests and Practical Methods of Control; 1910.

³Burke, H.E. (in manuscript); The Economic Importance, Ecology and Control of the Pacific Flathead Borer; 1926.

⁴Lipman, C.B. and Gordon, A.; Science, N.S., Vol. LXIV, No. 1668; Further Suggestions for the Application of the Lipman-Gordon Method of Tree Injection; 1926.

While the practicability of many of the methods of preventing barkbeetle attack and destroying broods that were mentioned in the foregoing appeared doubtful, they were of value as a basis for further investigations. They served as a starting point for experiments which were carried out in Crater Lake National Park and the adjacent Crater National Forest, in Oregon, during the period of insect activities in 1926 and 1927, the results of which are herein presented.

OBJECTIVES AND OUTSTANDING RESULTS
OF THE 1926 AND 1927 EXPERIMENTS

These studies were undertaken with the primary objects of discovering means to prevent attacks of the mountain pine beetle and of developing new methods of killing the broods before serious injury to the attacked trees resulted.

The objectives and prominent results of the experiments carried out during the two seasons are summarized in the following brief statements:

1. Experiments to prevent attacks of the mountain pine beetle on living lodgepole pine trees

The prevention of attacks on living trees was attempted by the use of three separate methods, viz., by the application of sprays, by screening the trunks of trees and by injecting substances into the trees.

The results secured with the sprays were largely negative. None of them was entirely successful in preventing attacks, though creosote, kerosene, pyridine, Dupont #43 and sodium fluoride gave a medium degree of protection to trees in the open for-

est. All the sprays failed to prevent attacks when beetles were caged with sprayed green material.

The experiments with screen barriers showed that this method of preventing attacks is not practical for general use. It is not feasible to screen the entire trunks of trees, and since attacks are often made on the unscreened boles in the crowns, which usually kill the trees, screen barriers are not always effective.

The injection of trees without resultant mortal injury failed to immunize them ^{to} from attack. Most of the substances used were neutral in action, and did not perceptibly affect either the beetles or the trees. Injections of arsenic, however, are quickly followed by the death of the treated trees. The fact that these trees were not subsequently attacked by insects is of no value in saving them, since the lethal action of the arsenic is more rapid than the injury resulting from insect attack. On the whole, the results secured with injections were entirely negative in the main objective, and showed not the slightest measure of success with the materials used.

2. Experiments to kill beetle broods in infested trees

This phase of tree protection from barkbeetle damage was attempted by injecting poisons, or repellent substances, into the trees after attack.

Tests with this method of killing broods were made on the mountain pine beetle in lodgepole pine and on the western pine beetle in yellow pine.

The results were much the same with the various substances used. None was entirely successful, and many failed to affect the developing broods in the least degree. Of the substances used sodium

arsenate is the most promising. The results of injecting this poison into lodgepole pine trees were conflicting. Broods in many of the treated trees were not affected, whereas in others a high percentage of mortality resulted. Mortality in these cases seemed to be due to the early drying out of the inner bark and cambium.

The results from arsenic injection of yellow pine trees infested with the western pine beetle were similar. Mortality of about 30 per cent of the individual broods followed these injections.

The results of these experiments were mostly negative. None of the substances used is recommended for general use. It is also doubtful if the method can be made practical, since it appears impossible to inject sufficient poison into the trees to affect the broods directly.

3. Killing trees with arsenic to prevent subsequent insect attack and the inhibition of blue stain induced by barkbeetle attack

The attainment of these objectives was sought by employing the injection method of tree treatment. The poison used was sodium arsenate. Both lodgepole and sugar pine trees were treated.

The treated lodgepole pine trees died within 10 to 15 days after injection. The lethal action of the arsenic was slower in injected sugar pine trees. Death of these trees occurred in from 15 to 25 days after injection.

Some of the treated trees of both species were felled for traps after they had turned red. Untreated green trees adjacent to the tests were also felled for traps.

The results of this treatment of green trees were outstanding. The method was effective in preventing insect attacks. Not one of the treated trees left standing, or those felled, was attacked by any species

of barkbeetle or woodborer to which they are ordinarily subject.

All the untreated traps were fully infested.

The seasoning of the infested trees that were felled was very rapid. At the close of the season, in October, they were well dried out, though the bark was still intact. None of the treated trees had developed blue stain up to the close of the first season. However, treated trees that were left standing had an abnormal moisture content at the close of the season, and these trees may yet develop blue stain.

This method of preventing insect attacks holds great promise for the treatment of stock intended for rustic woodwork and other similar purposes which is subject to deterioration resulting from insect damage.

The prevention of blue stain in the sapwood is another noteworthy benefit to be derived from the treatment, if these stains are prevented until the season^{ing} of treated standing trees is complete. Since sufficient time had not elapsed to establish this result definitely, the treatment cannot be finally recommended until further experimentation proves that the preliminary results are permanent.

DETAILS OF EXPERIMENTSPREVENTION OF ATTACK

SPRAYING

Lodgepole pine trees were sprayed with various substances to prevent attacks of the mountain pine beetle. These spraying operations were carried out during the main attack periods in July and August of both years. During these periods sufficient beetles emerged in the forest to insure maximum attacks.

Both standing trees and felled logs were sprayed in the open forest, and as a check on the outside tests, green sections of sprayed logs were enclosed in wire screen cages into which adult beetles were liberated.

Of the standing trees sprayed, only those that had received a few initial attacks were utilized. By selecting only such trees, the possibility that they would not have been attacked by the beetles even had they not been sprayed was obviated. Two series of spraying tests on standing trees were carried out. In the first series the beetles in the few attacks at the time of spraying were not molested. To overcome any complications that might arise from leaving beetles in the trees, a different procedure was employed in the second series of tests. The beetles making the first few attacks in these trees were dug out of their galleries and killed before the sprays were applied. The trunks of these trees were sprayed to a height of 20 feet. It was not possible to spray above this, ^{point} due to the limitations of the equipment used, nor was this considered necessary, since the first attacks of the mountain pine beetle on lodgepole pine are always made below this point.

The trunks of the felled logs were sprayed only in spots, so as to show selection by the beetles in case they were attacked at all. These trees were not prepared in any way after felling, and the limbs and tops were left intact. The sprays were applied to all this material by means of a portable hand sprayer and the sprayed portions were given a thorough coating.

Cedar Oil

Application: Both standing and felled trees in the open forest were sprayed as well as green sections in enclosed cages. The commercial grade of the compound was used in undiluted form.

Results: All sprayed trees and sections of logs were fully attacked and all developed normal broods. The cedar oil did not repel the beetles to the least degree, all attacks being continued without interruption.

Crude Creosote

Application: Both standing and felled trees were sprayed with undiluted creosote. The foliage of saplings was also sprayed to check the effect of the creosote on the foliage.

Results: Those trees from which the beetles making the initial attacks were not removed were fully attacked within ten days. The trees that were freed of beetles before the spray was applied, and also the trap trees, were successfully protected from attack. However, the spray burned the foliage severely, and the trees sprayed the first year died before the following season. The small trees that were sprayed for checks were killed by the creosote.

Kerosene

Application: This spray was used full strength and also diluted with equal parts of water. Standing and felled trees were sprayed, as well as sections in closed cages.

Results: Of the trees sprayed the first season about 50 per cent were protected from further attack. All the trees treated the second season, including the trap trees and the green sections in the closed cages, were fully attacked. The results with the diluted spray were the same as with the full strength solution; neither noticeably affected the foliage.

Pyridine

Application: This substance was used full strength, mixed with equal parts of kerosene, and with equal parts of water. Standing trees, felled trees and caged checks were sprayed.

Results: Same as in the case of kerosene alone. In the tests of the first year some of the sprayed trees that had been freed of the initial-attack beetles were protected; however, the negative results of all tests made the second year showed that these first

results were largely accidental. No difference in results could be detected between the undiluted pyridine and the sprays diluted with kerosene or water.

Petroleum Oils

Application: Petroleum oil sprays, both light and heavy grades, which have been successfully employed in combating orchard insects, were given a trial on standing trees in the first year's experiments. Two sprays of different strengths were used; one was compounded of 4 ounces of the oil emulsion to 1 gallon of water, while the other was double this strength, or 8 ounces of oil to 1 gallon of water.

Results: Entirely negative. All trees sprayed were fully attacked within a week after spraying. Since these solutions offered no hope of success in preventing attacks they were not used in the experiments conducted in 1927.

Dupont #43

Application: Both standing and felled trees, also green sections of logs in control cages, were sprayed with this insecticide, which is a proprietary article. It comes in the form of a light, dry powder, but can be suspended in water and used as a spray. Two tests were made each year. The mixture applied to the trees of the first test was made by agitating 125 gr. of #43 in 2 lit. of water. The strength used in these second tests was double this. One liter of solution was sprayed on each tree treated.

Results: A high degree of protection from attacks was secured with this insecticide in the experiments of 1926. In these tests all the trees that had been freed of the initial-attack beetles before spraying were not subsequently attacked. The trees in which these beetles were left were not so well protected, though not heavily attacked. However, the results obtained in 1927 with this spray were negative, as all standing trees, as well as the felled ones, were heavily attacked. The check sections placed in the closed cages were attacked before the spray on them had dried.

Orthodichloridobenzene

Application: This substance was used full strength in the experiments of 1926. One liter was applied to each tree sprayed, which had been attacked near the base by a few beetles. It was not used in the 1927 tests.

Results: The spray when first applied checked the attacks. However, this effect was only temporary, and all the trees were fully attacked 17 days later.

Sodium Fluoride

Two tests with this compound were made each year, in all of which the fluoride was used in the form of a saturated solution. In the first series of tests standing trees were used and each tree was sprayed with one liter of solution. In the second series 2 liters were sprayed on each down tree treated. The water content of the spray soon evaporated after being applied, leaving a powdery deposit of sodium fluoride that covered the surface of the bark.

Results: The 1926 experiments with this spray gave very favorable results. While all the trees sprayed in these tests were later attacked by a few beetles, none of them was fully attacked and many of the attacking beetles died soon after entering the inner bark. Some few deposited eggs which hatched, though many of the larvae died in the first stage. These favorable results, however, were nullified by the 1927 tests with this spray. In these last experiments felled logs and standing trees were sprayed, and in addition check sections were used in the control cages. All this material was fully attacked within one week after the sprays were applied. While many of the adult beetles making these attacks were killed before galleries could be extended, the results were negative insofar as prevention of attack was secured. There was no selection at all by the beetles between the sprayed and unsprayed areas on the felled logs.

Carbon Tetrachloride

Application: Standing trees were sprayed with full strength carbon tetrachloride in the tests of 1926. The few beetles that had attacked these trees were dug out of about half the trees sprayed, but left in the others.

Results: Entirely negative. The spray evaporated almost immediately after it was applied. It did not check the attacks and all trees were fully infested 7 days later.

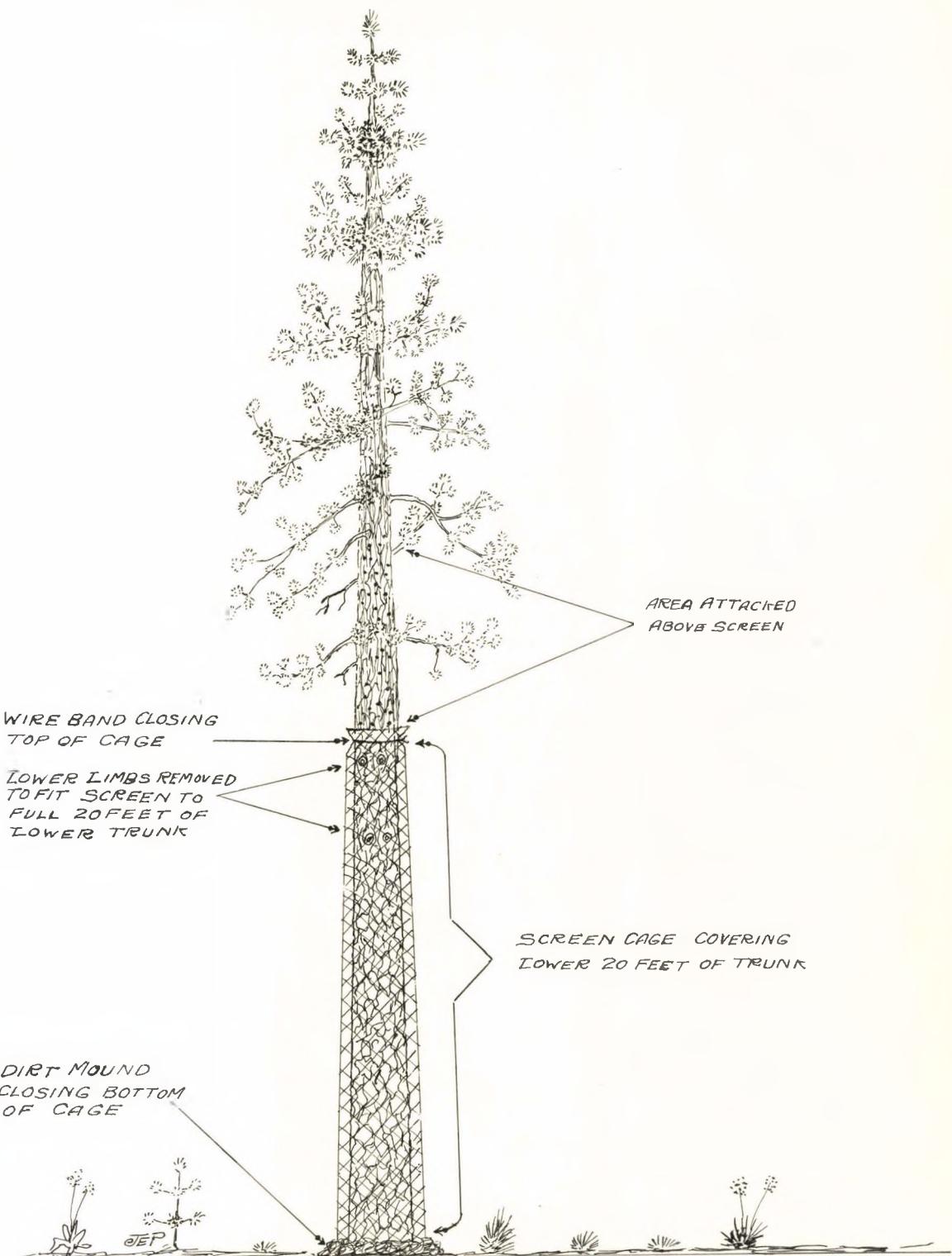
Sodium Chloride

Application: Both standing and felled trees and check sections in control cages were sprayed with a saturated solution of common salt. This spray remained as a fine white deposit on the bark of the trees after the water content had evaporated.

Results: No protection whatever from attack was secured with this spray. Beetles attacked while the spray was still wet and continued to do so after it had dried.

SCREENING

Protecting the trunks of trees from insect attack by means of mechanical barriers erected around them has been practised on orchard and deciduous shade trees. Screening the lower trunks of lodgepole pines to prevent attacks of the mountain pine beetle was experimented with, since this had frequently been advocated; although any mechanical barrier erected around a tree is a more or less unsatisfactory means of preserving it even if productive of the desired result. About the only forest trees any one would wish to protect by such means are those of high aesthetic value, and barriers erected about them would greatly detract from their appearance. The method is of course impracticable in commercial stands.



METHOD OF ERECTING SCREEN BARRIERS AROUND BASE OF LODGEPOLE PINE TREES TO PREVENT BARKBEETLE ATTACKS.

Since the mountain pine beetle makes its first attacks on the lower trunks of lodgepole pines, it was believed that these trees could be successfully protected by screening only this portion of the trunks.

Ten trees were screened during the two seasons in the following way: the lower limbs were cut off flush with the bark. The barrier used was galvanized wire screen of 16 mesh in sections 20 feet long and 40 inches wide. This material was wrapped the narrow way around the trunks of the trees and tacked along the overlapped edges. It formed a continuous barrier from the ground to a height of 20 feet on the trunk. In addition to the ten trees treated in this way, another set of ten trees were each partially screened by tacking the wire mesh in narrow strips on a part of the circumference of the trunks. The screened arcs in this set of trees ranged from one-quarter to three-quarters of the circumference to 20 feet from the ground.

The trees treated had all been attacked near the base by a few beetles, showing that they had already been selected for attack. Before the screens were placed around the trees these beetles were removed and killed.

Results

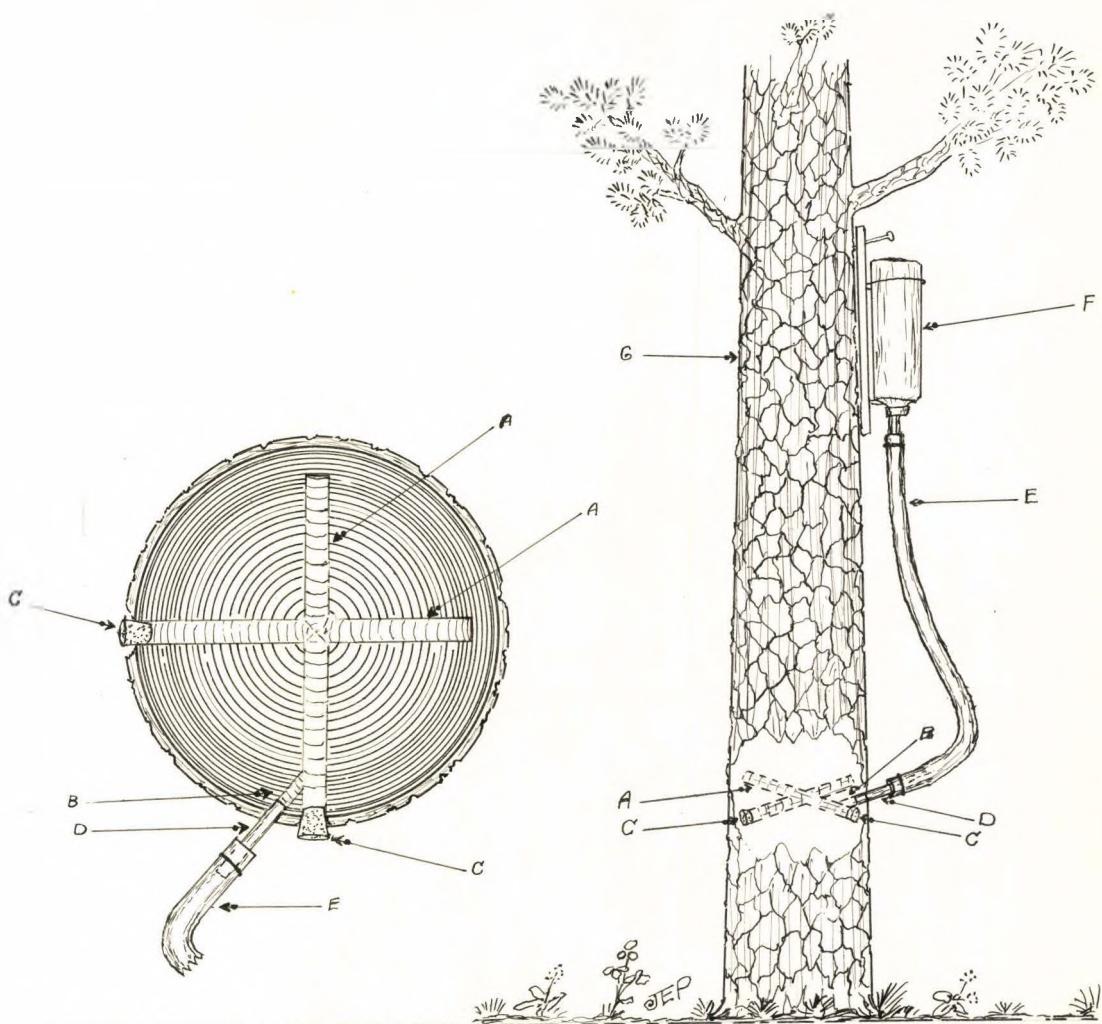
During the period of attack many adult beetles were observed crawling about on the outside of the screens trying to get through to the enclosed trunks. The ten trees that were only partially screened were all attacked on the unscreened portions, and all of them died from these attacks. The entrance holes on these trees were all made in the unscreened bark, although the galleries were extended laterally under the screened portions. Of the ten trees that were completely screened to a height of 20 feet, 8 were attacked above the screens. The other two trees in this

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set were entirely protected from attack. The attacks above the screens ranged from 3 to 10 feet higher than the screens. All the trees were not completely encircled by the attacks, but their tops were killed and all finally died.

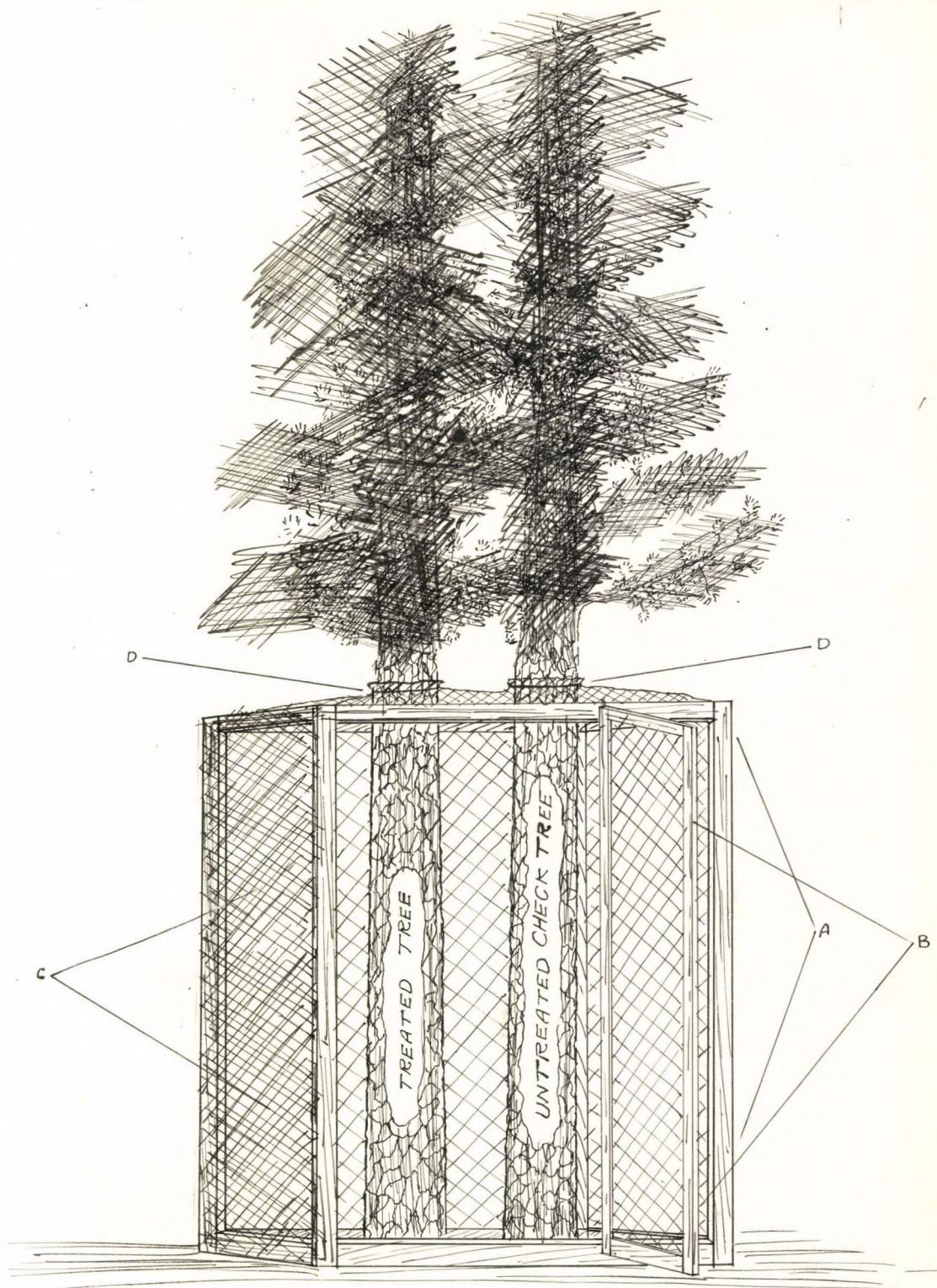
INJECTION

Experiments in the inoculation of lodgepole pine trees to immunize them to attacks by the mountain pine beetle were carried out during both seasons. The method employed is a modification of the Lipman-Gordon method of tree injection, and consists of injecting chemical and other substances into the trees by means of specially constructed apparatus. The injections were made as follows. Auger holes either one-half or one inch in diameter were bored into the trunk of each tree treated at a point about 2 feet above the ground. It was found in practice that injection was more rapid with the larger holes and when two were made from quartering sides of the tree and intersecting in the center, as shown in Fig. A of the following sketch. These holes were plugged at the open end with one-inch corks. One of these was tapped by a half-inch hole drilled through the sapwood, into which was driven a brass tube one-half inch in diameter and 6 inches long. To the outer end of this tube was attached a half-inch rubber hose, which extended 3 feet up the trunk and was attached by means of a short tube to the cap of a Mason jar (or other suitable container), which was hung on the tree in an inverted position. This jar, or other container, held the injecting solution. This apparatus as it was installed in use is shown by Fig. B in the following sketch:



APPARATUS USED FOR INJECTING TREES AND METHOD OF BORING TREES FOR SOLUTION RESERVOIR.

- A - Tree reservoir: Auger holes 1 inch in diameter.
- B - Tapping hole: Auger hole $\frac{1}{2}$ inch in diameter.
- C - One inch corks plugging open ends of auger holes.
- D - Brass nipple; $\frac{1}{2}$ inch in diameter and 6 inches long.
- E - Rubber hose connecting nipple with solution container.
- F - Solution container. (In this sketch 1 qt. Mason jar).
- G - Injected lodgepole pine tree.



TYPE OF CAGE USED IN CONTROLLED EXPERIMRNTS WITH SPRAYS AND INJECTIONS.

These cages were 7 feet high, 5 feet wide, and 4 feet deep.

A - Wood framework. Stock 2" x 4" pine.

B - Door. 1" x 2" materials

C - Wire cloth screen of 18 mesh covering entire framework.

D - Wire collars securing screen to trunks of caged trees.

In some of these experiments it was desired to have check trees for a comparison of results and to make certain that both the injected trees and the checks would be subjected to attack. To insure these conditions, caging the trees selected was resorted to. A cage, consisting of a wooden framework covered with fine-mesh wire screen, was built around both treated tree and check tree. After one tree within a cage was injected, sections from an infested tree from which beetles were emerging were put inside the cage and the latter closed. The beetles that emerged were confined in the cage and in this way induced to attack the trees. A comparison of their selection determined the effectiveness of the inoculation of the injected trees.

In addition to these controlled experiments a number of trees in the open forest were injected with the same substances. In this test, as in others, the trees selected had been attacked by a few beetles, which were dug out and killed before the trees were injected. These injection experiments were carried out during the periods of maximum attacks in both years.

Carbon Tetrachloride

Application: Two liters of a solution made by mixing carbon tetrachloride with equal parts of water were injected into each tree treated. Both caged and uncaged trees were treated. From 7 to 9 days were required for the trees to take up the full amount of the solution. Absorption was much more rapid during the first few days following the tapping of the trees than during the latter part of the injection period. Three days after the caged trees were injected, infested material was put into the cages.

Results: Caged-tree tests. Both treated and check trees in all these tests were attacked within 4 days after the infested material was put into the cages. No selection was shown by the beetles in attacking these trees, and about an equal number of attacks were made on each. Within 7 days after the first attacks were made in the cages, beetles from the forest were attacking the trees above the cages.

The results from the tests made in the open forest were no better; all these trees were fully attacked within one week.

Cedar Oil

Application: Both caged and uncaged trees were injected with cedar oil solution, made by mixing the compound with an equal amount of water. Each tree was injected with 2 liters of the mixture. The absorption of this solution was quite rapid and the injection of all trees was complete within 3 days. Infested material was placed in the cages on the fourth day after the injections were started. At this time the odor of the cedar oil was quite pronounced, even at a distance of 10 feet from the trees.

Results: Entirely negative. Within the cages the injected trees were as heavily attacked as the checks. The results of the uncontrolled tests were the same. All these trees developed normal broods.

Sodium Arsenate

Application: Both caged and uncaged trees were treated. Each injected tree was given 2 liters of solution, which however varied in strength for the different tests. The strength used varied from 2 gr. to 15 gr. of dry sodium arsenate to 2 liters of water. The average rate of absorption of this amount of solution was 2 days.

Results: In the case of the caged trees the results were absolutely negative, as they were all attacked within three days. No selection was made by the beetles between the injected trees and the checks. However, an entirely different result was secured from the uncaged trees, none of which was attacked after being injected. While the primary purpose of these tests was achieved it was of no practical benefit, as all the trees died from arsenate poisoning within two weeks.

Sodium Chloride

Common salt in the form of a saturated solution was injected into trees in both the controlled and uncontrolled tests. Two liters of the solution was given each tree treated.

Results: These injections did not noticeably affect the trees nor repel attacks. All the treated trees were normally attacked, and all developed normal broods.

Red Fir Extract

Application: Caged and uncaged trees were injected with 2 liters each of solution made by boiling red fir (*Abies magnifica*) needles in water; this decoction was dark brown in color and about the consistency of strong tea. The absorption of this extract was very slow, and only a small amount could be injected into each tree. From 9 to 12 days were required for the absorption of 1 liter of the solution; after that the action ceased and no more entered the tree.

Results: Unsatisfactory; all the treated trees were attacked, though some of them only lightly. It is believed, however, that this result was due to poor emergence from the infested material in the cages, and was accidental in the uncaged tests, since in all other injected trees the attacks were normal. The brood development in the trees normally attacked was complete.

Bitter Aloes

Application: Both caged and uncaged trees were injected with a solution made by boiling 500 gr. of bitter aloes powder in 3 liters of water. It was attempted to inject 2 liters of this solution into each tree treated. However, the trees refused to absorb more than 1 liter each, and the rate of absorption was slow, requiring about 10 days for this amount to enter the tree.

Results: No better than those secured with the fir solution. All the treated trees were attacked and the brood development was normal.

ON RESULTS

GENERAL REMARKS

The general results of the experiments carried out to prevent attacks of the mountain pine beetle on lodgepole pine trees were largely negative.

Of the sprays used for this purpose those possessing any value at all are:

Crude creosote - Gives a medium degree of protection from attack, but is injurious to the trees and kills the foliage with which it comes in contact.

Kerosene - - - - Fifty per cent of the trees sprayed the first year were not subsequently attacked. However, as all the trees sprayed the second year were fully attacked, these first results may have been largely accidental.

Pyridine - - - - The results secured with this spray were similar to those with kerosene.

Dupont #43 - - - - - The early results secured with this material were quite promising, but failure to prevent attacks in 1927 proves that it cannot be depended upon.

Sodium Fluoride - The behavior of this spray was the same as that of the Dupont #43.

All these sprays except the creosote were used in the controlled experiments with sprayed sections of green logs placed in cages containing emerged adult beetles. None of them prevented the sprayed material from being attacked. The other sprays used—cedar oil, petroleum emulsion oils, orthodichloridobenzene, carbon tetrachloride and sodium chloride—were of no value in preventing attacks.

The prevention of attacks by means of mechanical barriers is not a practical method for use on forest trees, since in order to be successful almost the entire bole of the tree must be enclosed with the screen or other material. This would necessitate the removal of the greater part of the limbs, which is an undesirable treatment of park trees or trees of aesthetic value. The method is impractical in commercial forests.

The results of the efforts to immunize trees from attack by injecting them with substances foreign to the trees, without resultant injury to them, show not the slightest measure of success with the substances used. All the materials failed to prevent attacks in the controlled tests where beetles were forced to attack the injected trees. All the trees in the open forest that were injected with sodium arsenate were rendered immune to attack; but since the arsenic killed these trees much more quickly than the beetles could, this substance is of no practical value in saving trees from insect attack. However, since the injection of trees with the apparatus employed is quite feasible, it seems reasonable to suppose that some substance may be found that will have the desired effect. Only further experimentation in this field will determine this point.

KILLING OF BARKBEETLE BROODS BY TREE INJECTIONS

The object of these experiments was to kill developing broods of barkbeetles in infested trees by injecting sodium arsenate and other substances into the trees after they had been attacked. It was believed that the primary effect of such treatment would be either a rapid drying out of the cambium or the production of chemical changes in it, either of which would result in high mortality in the broods during the stages of early development. Since it is suspected that blue stain is essential

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to the development of the broods of these beetles, it was believed that the inhibition of this fungus in attacked trees would result in mortality of the broods. The killing of broods by injection of poison into the trees and the prevention of blue stain were the two objects of these further experiments.

The tree injections were made in the same way, and with apparatus of the same type, as those given in the preceding section for the prevention of attacks. In each instance these injections were made as early as possible after the trees were attacked in order to secure the maximum effect before brood development had progressed too far for their effectiveness.

The lodgepole pine trees treated were infested with the mountain pine beetle, and were located in Crater Lake Park or in the adjoining areas of the Crater National Forest. The yellow pine trees that were infested with the western pine beetle, Dendroctonus brevicomis, were located in the southern part of this forest.

MOUNTAIN PINE BEETLE IN LODGEPOLE PINE TREES

Sodium Arsenate

Application: Standing trees infested with broods consisting of parent adults, eggs and young larvae were injected with solutions of sodium arsenate of different strengths. The separate tests consisted of the treatment of individual trees with solutions made by dissolving in one liter of water the following amounts of dry sodium arsenate:

A -	1 gram
B -	2 grams
C -	6 "
D -	10 "
E -	50 "
F -	100 "

The injected trees absorbed the 1 liter of solution given them in from 2 to 11 days. The rate of absorption had no relation to the strength of the solutions used, but was regulated by the structure of

the individual trees. Those trees that had made a rapid growth, indicated by the relatively large amount of summer growth in the annual rings, absorbed the solutions in the shortest time. The fading of the foliage, indicating the dying of the trees, depended directly upon the amount of arsenic injected into them. The reaction of the foliage to the different strengths of the solutions employed was as follows: "A" strength; fading of the foliage began in from 11 to 15 days, but it did not all turn red until after 30 days. B; foliage began fading in from 8 to 12 days and was all red 30 days after injection. C; fading began in from 4 to 6 days and was complete within 15 days. D; reaction showed very little departure from C, E and F; fading began in from 4 to 6 days after injection and all was faded in 10 to 12 days. Tests with solutions of less than 1 gram of arsenic in 1 liter of water showed that the smallest lethal dose required to kill an average-sized lodgepole pine was one-half gram. The above tests also showed that the maximum dose necessary is about 10 grams.

Results: Aside from the killing of the treated trees by arsenic poisoning, the results of these tests were conflicting. Out of a total of 50 separate broods treated, 44 showed no distinct reaction to the poisoning of the trees, and developed normally. A high mortality occurred in the other six broods, which could be attributed only to the early drying out of the cambium. Blue stain developed in all the injected trees, and because this fungus was not inhibited no information was secured on the effect of its absence. By the end of the season the inner bark and sapwood on many of the injected trees was considerably drier than that of untreated infested trees. In the other trees treated there was an abnormally moist condition of the inner bark. A comparison of the trees exhibiting these opposite conditions showed that those which contained an excessive amount of moisture were thick-barked trees, and that the thin-barked trees quickly seasoned. On the whole, the results of these tests, insofar as effecting mortality of the developing broods by the injection of arsenic into infested trees, must be considered negative.

Copper Sulphate

Application: Infested trees were injected with solutions of copper sulphate varying in strength. From 50 to 300 grams of the sulphate were dissolved in 1 liter of water. Each tree treated was given 1 liter of solution. The purpose of this experiment was to prevent the development of blue-stain fungus by the injection of this fungicide into the sapwood. All the treated trees were injected during the attack period and before any evidence of the fungus had appeared.

Results: Of the 25 tests made not one prevented the development of blue stain. There was no visible reaction of the trees to the copper sulphate injected. The normal development of the beetle broods was not affected in the least degree.

Bitter Aloes

Application: The injection of a strong solution of bitter aloes was made for the purpose of impregnating the cambium with this bitter substance and rendering it objectionable as food for the larvae. The attempt to inject 1 liter into each tree treated was not successful, as none of the trees absorbed the full amount. However, from one-half to three-quarters of a liter was forced into each tree. The rate of absorption was slow, although sufficient entered the cambium on the main trunks to give it a distinctly bitter taste.

Results: The bitter flavor given the cambium was apparently not objectionable to either the adults or the larvae of the beetles, for the gallery construction of the former and the feeding of the latter were normal in every way. All the 25 trees treated developed normal broods.

Sodium Chloride

Application: One liter of a saturated solution was injected into each tree treated. The rate of absorption was fairly rapid, and each tree took up the entire amount given it.

Results: Entirely negative. These injections did not affect the normal development of the broods in any way.

Water

Application: Infested trees were injected with water to determine the effect of excess moisture on attack and subsequent brood development. The injections were started during the initial attack period, and were continued until the trees ceased to absorb the water. The total amount of water absorbed by these trees during a 30-day period (from August 1 to September 1) varied per tree from about 3 gallons to 5 gallons.

Results: The behavior of the beetles in these trees did not vary from the normal. Attacks were not checked and the later development of the new generation was not affected.

WESTERN PINE BEETLE IN YELLOW PINE TREES

These injection experiments were carried out in the late fall of 1926. They were located in the extensive yellow pine stands in the southern part of the Crater National Forest.

Sodium Arsenate

Application: Average-sized yellow pine trees infested by the western pine beetle were each injected with 2 liters of sodium arsenate solutions. The three different amounts of arsenate per each 2 liters used were 7, 15 and 30 grams. At the time the injections were made the beetle broods consisted of parent adults, eggs and ~~larvae~~ very young larvae. These injections were made in October, although the trees did not fade until the following April.

Results: Following emergence of the new broods in May 1927 these trees were felled, and the exit holes in the bark were counted and compared with similar data from adjacent untreated trees. The average number of exit holes per square foot of bark from the injected trees was 61, and from the check trees 37. These data show that more beetles developed in the untreated trees, indicating that mortality of about 30 per cent of the broods occurred in the injected trees. However, since fluctuations fully as great occur under normal conditions, these data are not conclusive.

GENERAL REMARKS ON RESULTS

The experiments in the injection of chemical and other substances into infested trees to check attacks and kill the developing broods of barkbeetles have not so far resulted in the discovery of any substance which is effective. The first tests in 1926 with sodium arsenite indicated that broods of the mountain pine beetle in lodgepole pine would succumb to such treatment. However, later and more thorough research showed that these first results were largely fortuitous.

It is somewhat doubtful if the method could ever be successfully applied to some trees after attack, even if substances are found that will kill the broods, since there is such a short period between attacks of these beetles and the resultant mortal injury to the trees. For any substance to be successful it must have the following properties: it must kill the attacking beetles and also the broods in a very early stage of development, and its lethal action must be confined to the beetles and not include the trees. However, the field has by no means been covered by these preliminary experiments, and it is hoped that further experimentation and work in the field will be done. Substances may be found that will kill the broods; and even if the attacked trees cannot be saved, these will at least have great value as agents in controlling the beetles.

KILLING TREES WITH ARSENIC TO PREVENT SUBSEQUENT INSECT ATTACK

In the experimental work with tree injection carried out in 1926 it was noticed that barkbeetles and wood-boring insects did not subsequently attack lodgepole pine trees that had been killed by arsenic. If further experimentation proves that this treatment may be depended upon to immunize logs from insect attack until fully seasoned, this method would meet a practical need in treating logs for various purposes. During the 1927 further experiments in this field were carried out, the method being tested on both lodgepole and sugar pine. The results of these experiments show that green trees killed by injecting arsenic into them in sufficient quantity to cause quick death are thereafter immune from attack of all insects to which they are ordinarily subject. The practical value of this treatment is apparent in the preparation of logs to be used in the construction of log buildings, rustic woodwork, bridge timbers, and other uses for which unpeeled timbers are required. Other channels are indicated for the method, such as quick killing of trees on land to be cleared, and killing and pre-seasoning of commercial trees prior to logging. In the later case tests with the method have so far shown that the killed trees do not develop blue stain, which is of great significance to lumbermen.

Green lodgepole and sugar pine trees of average size were treated. The mode of injection was the same as in the other injection experiments carried out. However, the solution containers used for injections of the sugar pine trees were considerably larger, being tin cans of 5-gallon capacity.

LODGEPOLE PINE TREES

The injected trees ranged from 10 to 18 inches in diameter. They were located in an infested area, where they were subject to attacks by the mountain pine beetle, the Oregon engraver beetle and various species of woodboring beetles. These trees were treated in July and August, during the period of greatest insect activity.

The strength of the injected solutions varied from 1 to 10 grams of sodium arsenate to each liter of water. These amounts of arsenic were sufficient to kill the trees in from 10 to 15 days. Uninjected green trees were felled in close proximity to the treated ones, in order to check the relative selection by the insects which ordinarily attack this species. A number of the treated trees were also felled after they were injected, as a further check on attack.

Results: Out of a total of 20 treestreated, not one was attacked by any species of insect. The infested trees that were felled for traps were no more attractive than those left standing. All the green trap trees were fully attacked by both barkbeetles and wood-boring insects. At the close of the season, in October, all the treated trees that had been felled were well seasoned with the bark intact.

SUGAR PINE TREES

Sugar pines ranging in diameter from 20 to 36 inches were injected during the late summer and early fall. A total of 10 trees were treated with solutions which varied in strength from 100 to 500 grams of sodium arsenate to each 20 liters of water. The rate of absorption varied somewhat (8 to 16 days) with each tree treated. The average time required for the trees to take up the full 20 liters was 12 days. Foliage began fading 15 days after injection, and discoloration was complete

in 36 days. Ten green trap trees, ranging in diameter from 10 to 12 inches, were felled near the injected trees for checks on attack.

Results: The injected trees were all killed within a period of 30 days. An examination made in late October showed that none of them had been attacked by beetles. The green check trees were all attacked in September by the mountain pine beetle and Ips species. Blue stain had not appeared in the sapwood of the treated trees up to the close of the season in November, although it was well developed in the trap trees. Abnormal moisture of the inner bark was a characteristic condition of the injected trees.

GENERAL REMARKS

The experiments with arsenic as an agent for quickly killing forest trees and at the same time immunizing the logs from subsequent insect attack gave very satisfactory results in the treatment of both lodgepole and sugar pine. Although these were the only species experimented with, there is no apparent reason why the method would not be equally effective with other forest trees.

It is an inexpensive method of preventing insect attacks on logs for rustic woodwork and other similar purposes, and after treatment will permit the cutting of this stock at any season of the year. Its advantages for this purpose over the spraying treatment with creosote and other repellents is that no objectionable odor is left on the stock, and there is no discoloration of the bark surface such as results from the application of sprays.

Since blue stain did not develop in any of the trees treated, the method may have a large application in the killing and seasoning of standing trees prior to logging.